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AN ASSESSMENT OF THE HOVER PERFORMANCE OF THE XH-59A ADVANCING BLADE CONCEPT DEMONSTRATION HELICOPTER

May 1977

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This report documents a study of the hovering characteristics of the XH-59A helicopter, which was built to demonstrate the feasibility of the Advancing Blade Concept (ABC). The study examined in- and out-of-ground hover characteristics, aircraft and rotor figures of merit, and hover performance at 10- and 20-foot wheel heights. The XH-59A's performance is also compared to the performances of other Army helicopters. This indicates that the XH-59A performs better than other helicopters, largely because it lacks a tail rotor.

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PREFACE

In 1971, the Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, awarded a contract to the Sikorsky Aircraft Division of the United Technologies Corporation to design, fabricate, and test a research aircraft to demonstrate the feasibility of the Advancing Blade Concept (ABC). The first flight of the aircraft, designated the XH-59A, occurred in July 1973. In August 1973, the aircraft was extensively damaged in an accident, and flight-testing was stopped until rotor control modifications could be incorporated into a second XH-59A aircraft. A low-speed test program to verify the control modifications and to buildup airspeeds to 80 knots was successfully concluded in September 1975.

An envelope expansion test program was initiated in November of 1975. In April and June of 1976, two hover performance flights were conducted with the second XH-59A aircraft. This report provides the results of these flights.

Flight-testing and data reduction were performed by Sikorsky Aircraft personnel. On-site technical monitoring was performed by Eustis Directorate personnel.

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INTRODUCTION

The Advancing Blade Concept (ABC) rotor system is a coaxial, counterrotating, hingeless rotor system that features extremely stiff rotor blades and rigid retention of blades to the rotor shaft. This rotor system is incorporated in the XH-59A technology-demonstrator aircraft, Figure 1.

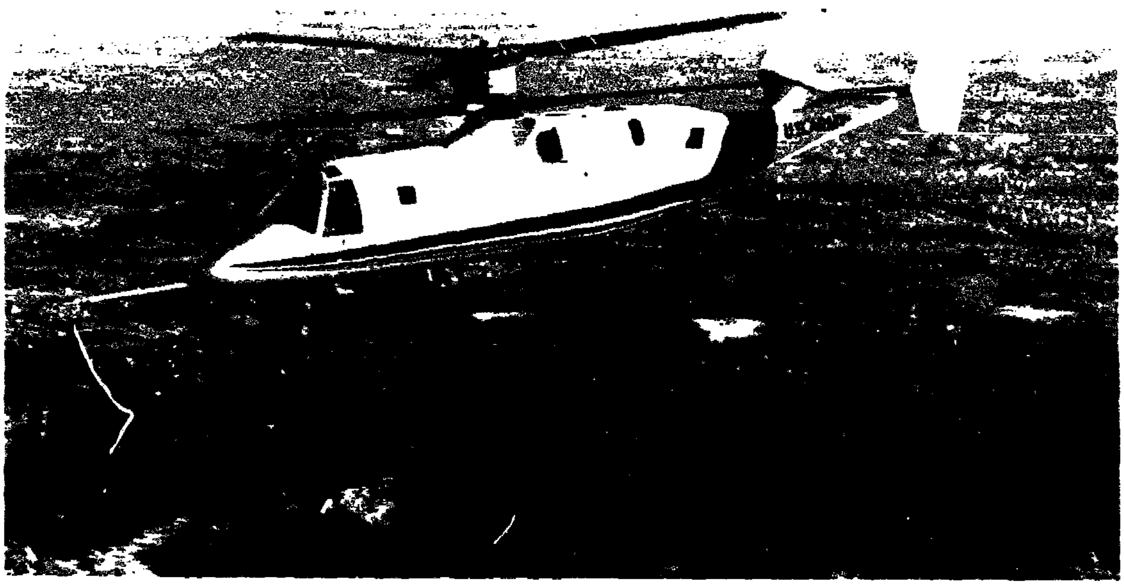

Figure 1. The XH-59A advancing blade technology-demonstrator aircraft.

The assessment of hover performance is important in the evaluation of the Advancing Blade Concept. This report takes a look at the hover performance of the XH-59A aircraft using hover data obtained during the initial envelope-expansion phase of the flight-test program.

XH-59A nondimensional hover data is shown for both the in-ground effect and the out-of-ground effect and is compared with U. S. Army operational helicopter test experience.

TEST AIRCRAFT

The primary characteristics of the XH-59A aircraft are given in Table 1.

TABLE 1. CHARACTERISTICS OF THE XH-59A AIRCRAFT

Number of blades, b	3 per rotor (6, total)
Number of rotors	2 (coaxial)
Chord (mean geometric - blade tapered), c	1.44 ft
Rotor radius, R	18.0 ft
Rotor solidity ratio (total, 6 blades), σ	0.127
Rotor disc area, A	1018 ft^2
Rotor RPM (100%), N_r	345 RPM
Rotor tip speed (100%), Ω R	650 fps
Rotor blade twist (nonlinear), θ_t	-10.0 deg
Design gross weight, W	9000 lb
Engine type	PWACL PT6T-3/T-400
Engine horsepower	1800 shp
Transmission rating (100% N_r)	1500 shp
Distance from bottom of wheels (oleos extended) to average rotor plane	10.8 ft

TEST TECHNIQUES

The hovering height of the XH-59A was established by using a rope with weights located at wheel heights of 10, 20, 35, and 75 feet. The pilot adjusted the height as directed by a ground observer. Tethered hover was not possible since the XH-59A aircraft was not equipped with an external attachment point. Gross weight variations were obtained by varying fuel quantities, which were accurately recorded. The weights on the hover rope were also accounted for.

Power was measured by standard engine torquemeters, and data was obtained at referred rotor speeds ($N_r/\sqrt{\theta}$) of 92, 95, and 100%. Winds were approximately two knots or less during the testing.

TEST RESULTS

OUT-OF-GROUND-EFFECT HOVER PERFORMANCE

The nondimensional out-of-ground-effect (OGE) hover performance of the XH-59A helicopter is presented in Figure 2. This data was taken at 35- and 75-foot wheel heights. The tip Mach number range was from 0.53 to 0.58. The tabulated data is contained in Table 2.

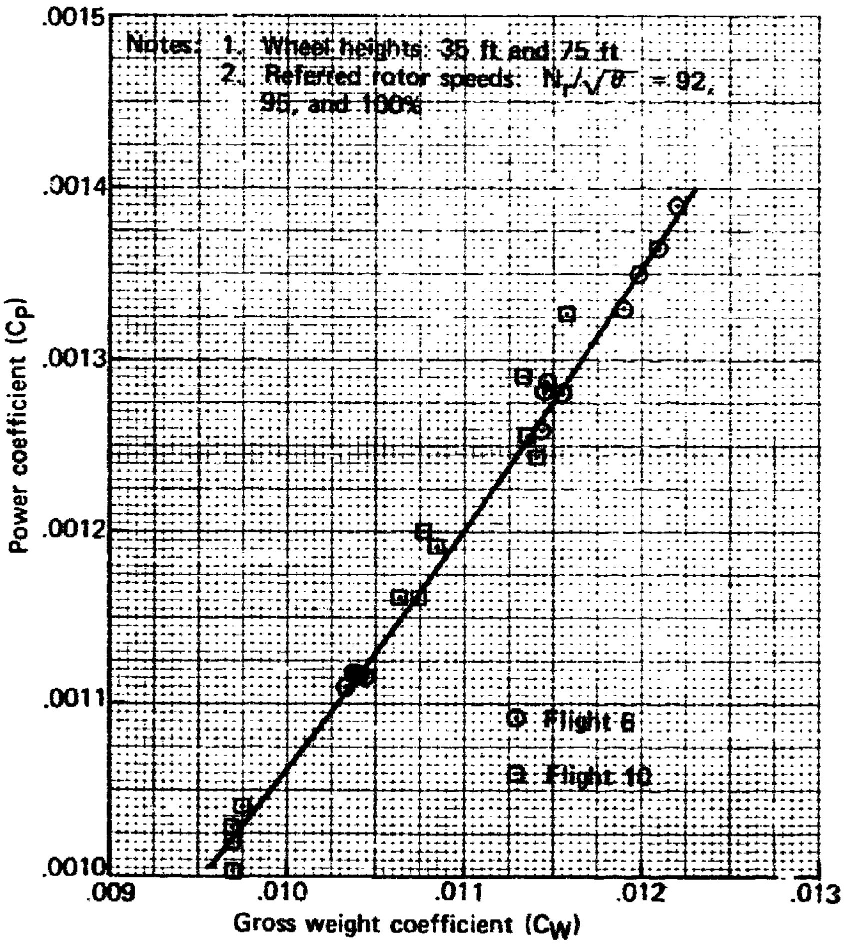

Figure 2. XH-59A out-of-ground-effect hover performance.

TABLE 2. OUT-OF-GROUND-EFFECT HOVER DATA

Wheel Height (ft)	Free Air Temp (^{o}C)	Pressure Altitude (ft)	Gross Weight (lb)	Total Engine Power (hp)	Rotor Speed, N_r (rpm)
		Flight 6			
35	6.9	-170	10,665	1297	314.7
	6.9	-168	10,650	1304	321.9
	7.1	-169	10,625	1327	339.1
	7.2	-169	10,625	1298	313.0
	7.0	-169	10,610	1315	322.4
	7.1	-166	10,600	1318	338.3
75	7.3	-132	10,600	1291	315.7
	7.2	-129	10,585	1288	322.9
	7.6	-126	10,550	1306	337.7
	7.5	-134	10,535	1276	316.0
	7.4	-131	10,520	1300	321.9
	7.5	-124	10,505	1309	338.6
		Flight 10			
35	9.7	-227	9968	1224	312.4
	9.7	-226	9953	1210	322.6
	9.8	-225	9943	1236	322.6
	9.7	-224	9933	1224	315.2
	9.8	-226	9923	1226	323.3
	9.8	-224	9908	1227	340.3
75	9.8	-185	9903	1162	313.9
	9.8	-192	9883	1188	323.4
	9.9	-186	9873	1191	340.1
	9.9	-187	9853	1174	314.4
	9.9	-189	9853	1195	324.2
	10.0	-180	9853	1210	340.0

The XH-59A helicopter hover data is shown in Figure 3 in relation to a number of representative Army helicopters. A representative expression for the OGE hover capability is given in Reference 1 by the equation $C_W = 1.93\ C_P^{\ 0.774}$ for the Army helicopters tested. This equation is used in Figure 3 for the dashed-line extrapolation of Army helicopter data to higher disc loadings. The high disc loading data for the CH-54B is from Reference 2, which used a CH-54B tethered at a 145-foot wheel height. The XH-59A data shows a gross weight coefficient, C_W, about 3% higher than the representative expression, while the CH-54B data shows a decreasing weight coefficient, C_W, as disc loading increases.

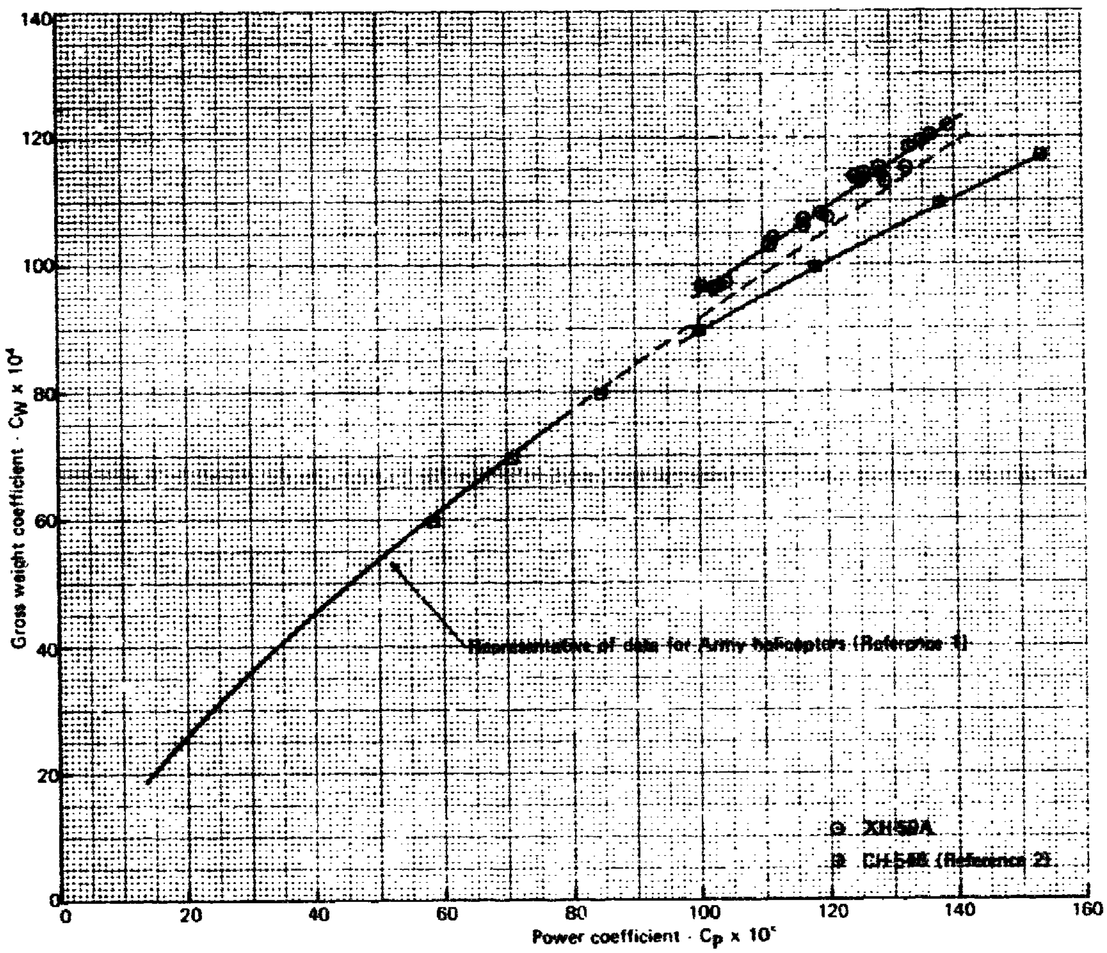

Figure 3. XH-59A and current Army helicopter out-of-ground-effect hover performances.

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[1] Lewis, Richard E., II, ARMY HELICOPTER PERFORMANCE TRENDS, Journal of the American Helicopter Society, Volume 17, No. 2, April 1972.

[2] Johnson, J. N., et al, LIMITED PERFORMANCE TESTS, CH-54B (TARHE) HELICOPTER, USAASTA Final Report 72-40, February 1973.

The XH-59A's aircraft figure of merit (M_A) is shown in Figure 4 in relation to the figure-of-merit trends for Army aircraft given in Reference 1. The CH-54B's aircraft figure of merit was calculated from nondimensional hovering performance given in Reference 2. The higher aircraft figure of merit for the XH-59A is attributed primarily to the deletion of the tail rotor and is above the 0.6 maximum value shown in Reference 1 for Army helicopters. The average aircraft figure of merit for the XH-59A was 0.67 for the data in the gross-weight range tested.

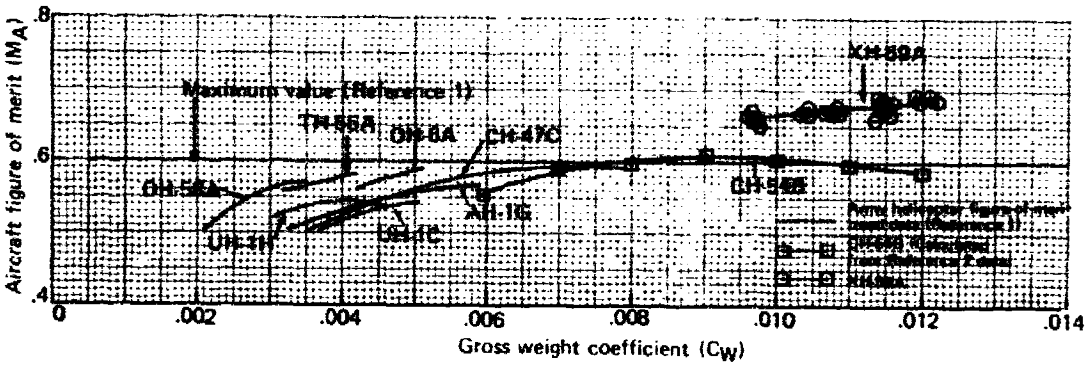

Figure 4. Aircraft figure-of-merit trends.

The rotor figure of merit (M_R) for the XH-59A can be assessed by estimating the vertical drag (download) and estimating transmission, accessory, and other losses. The vertical drag was calculated using the polar moment of inertia method of Reference 3, which is based on a single velocity distribution beneath a hovering rotor over areas of a characteristic shape and which yields a drag of 7.6% for an average helicopter fuselage and a drag of 5.0% for a cylindrical shape. Therefore, since the shape of the XH-59A is closer to that of a cylinder than to that of a standard helicopter, a download of 6% was considered representative, and the hovering rotor thrust was estimated to be 106% of the gross weight.

The XH-59A rotor figure of merit (M_R), based on the rotor power required, the 6% vertical drag ($T = 1.06W$), and an estimated 75hp transmission and accessory losses (rhp = shp -75), is plotted against the ratio of the thrust coefficient to the rotor solidity (C_T/σ) in Figure 5.

[3] Engineering Design Handbook, HELICOPTER ENGINEERING, Part One, Preliminary Design AMCP 706-201, August 1974, Paragraph 3-2.1.1.9.

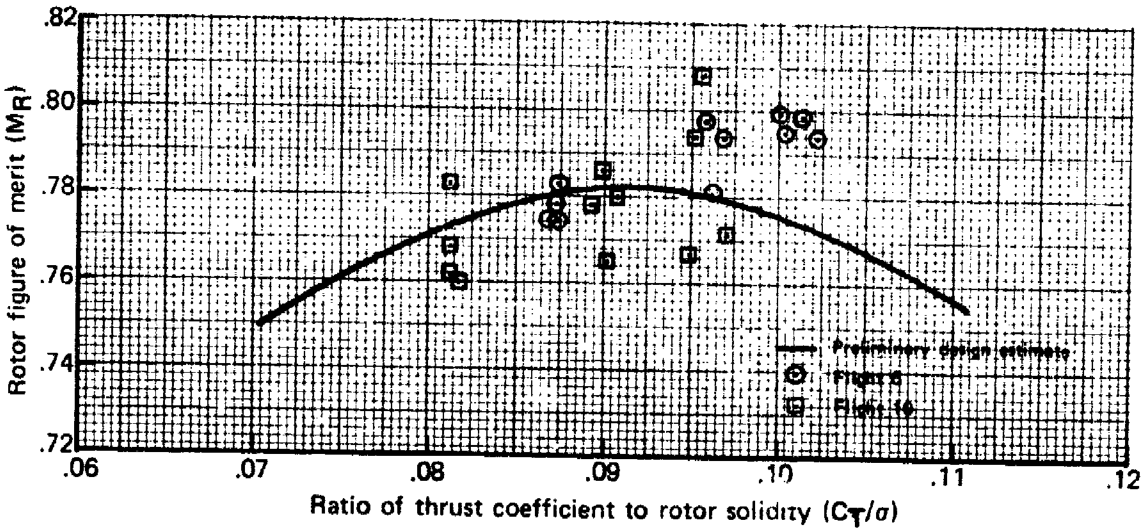

Figure 5. XH-59A rotor figure of merit.

IN-GROUND-EFFECT HOVER PERFORMANCE

The XH-59A nondimensional in-ground-effect (IGE) hover performance for 10- and 20-foot wheel heights is presented in Figures 6 and 7 respectively. The tabulated data is contained in Table 3.

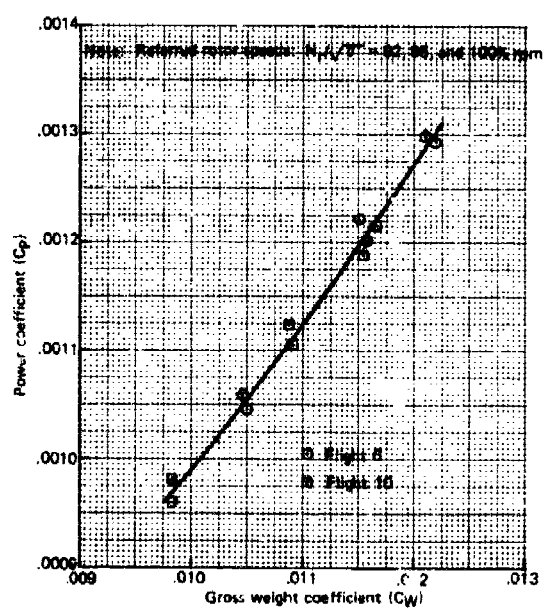

Figure 6. XH-59A hover performance at a 10-foot wheel height.

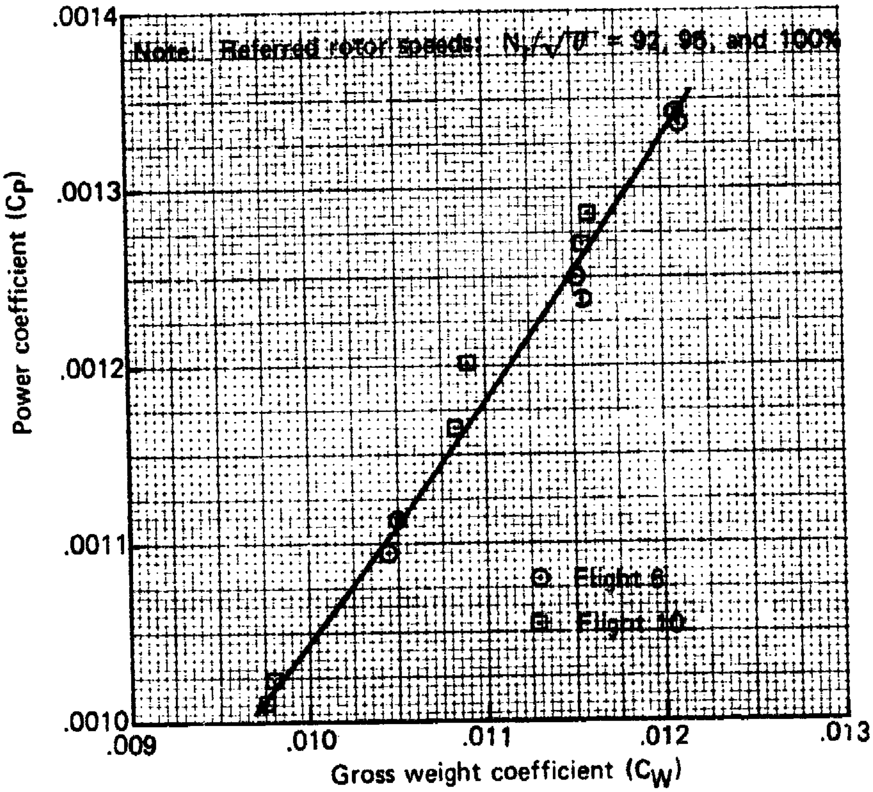

Figure 7. XH-59A hover performance at a 20-foot wheel height.

TABLE 3. IN-GROUND-EFFECT HOVER DATA

Wheel Height (ft)	Free Air Temp (^oC)	Pressure Altitude (ft)	Gross Weight (lb)	Total Engine Power (hp)	Rotor Speed, N_r (rpm)
		Flight 6			
10	5.9	-177	10,755	1225	314.0
	5.9	-178	10,725	1244	321.8
	6.2	-174	10,725	1255	339.5
	6.2	-173	10,705	1235	314.7
	6.4	-172	10,705	1221	321.9
	6.5	-177	10,690	1253	338.5
20	6.3	-175	10,695	1234	315.2
	6.3	-176	10,695	1288	323.0
	6.4	-178	10,685	1314	338.2
	6.3	-177	10,675	1276	314.8
	6.5	-180	10,675	1267	322.4
	6.6	-179	10,660	1299	338.7
		Flight 10			
10	9.6	-239	10,123	1136	313.7
	9.5	-235	10,063	1132	323.5
	9.6	-237	10,053	1169	340.0
	9.6	-248	10,043	1108	313.5
	9.7	-238	10,038	1149	323.3
	9.6	-240	10,033	1143	340.1
20	9.7	-238	10,023	1199	313.4
	9.6	-237	10,018	1220	322.5
	9.8	-241	10,013	1224	340.6
	9.7	-233	9,983	1177	313.0
	9.8	-239	9,983	1192	323.3
	9.8	-240	9,963	1206	340.4

A comparison of the XH-59A data with the Army aircraft in-ground-effect trends of Reference 1 is presented in Figure 8. The XH-59A data is easily within the scatter band of data for the representative Army aircraft. The approximate empirical relationship between ground proximity and thrust is from Reference 1:

$$T_{IGE}/T_{OGE} = 1.0 + 0.01 \times^{(1.0 + 0.5x)}$$

where $\quad x = 4.0 - 3.33\ Z/D$

and $\quad Z/D \leqslant 1.2$

The XH-5?A points on Figure 8 are calculated at a midrange power coefficient from Figures 2, 6, and 7 (C_P = .0012). The rotor height (Z) used for determining Z/D was the average height of the upper and lower rotors above the ground.

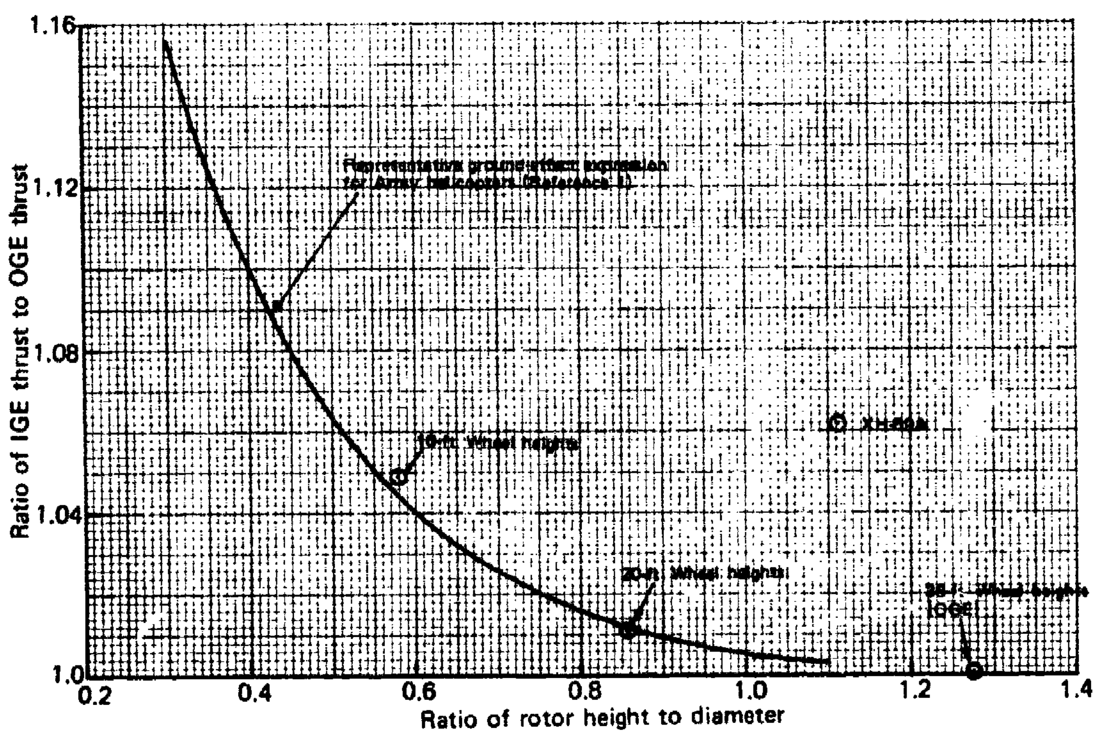

Figure 8. Ground effect trends.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Hover performance of the XH-59A Advancing-Blade-Concept research aircraft compares favorably with the hover performances of operational U. S. Army helicopters. The primary reason for this favorable hover performance is the absence of a tail rotor with its attendant power requirement.

RECOMMENDATIONS

For a final assessment of the XH-59A's hover performance capability with the ABC rotor, more detailed and accurate measurements should be made of downwash, engine power, power distribution between the two rotors, vertical drag, and power-train and accessory losses.

An external point for tether-hover testing would provide a better means for measuring the thrust of the helicopter. All future test helicopters should incorporate external attachment points for hover testing.

LIST OF SYMBOLS

A	Rotor disc area = πR^2, ft^2
b	Number of main rotor blades
C_P	Power coefficient = 550 shp/$\rho A\ (\Omega R)^3$
C_{P_R}	Rotor power coefficient = 550 rhp/$\rho A\ (\Omega R)^3$
C_T	Thrust coefficient = $T/\rho A\ (\Omega R)^2$
C_W	Gross weight coefficient = $W/\rho A\ (\Omega R)^2$
c	Rotor blade chord, ft
D	Rotor diameter, ft
IGE	In ground effect
M_A	Aircraft figure of merit = $.707\ C_W{}^{1.5}/C_P$
M_R	Rotor figure of merit = $.707\ C_T{}^{1.5}/C_{P_R}$
N_r	Rotor speed, rpm
$N_r\sqrt{\theta}$	Referred rotor speed
OGE	Out of ground effect
R	Rotor radius, ft
rhp	Rotor horsepower
shp	Engine horsepower
T	Rotor thrust, lb
W	Gross weight, lb
Z	Height of rotor above ground, ft
θ	Ambient temperature ratio = Ambient OAT,^{o}K/288.15^{o}K
θ_1	Rotor blade twist, deg

ρ	Atmospheric density, $slugs/ft^3$
σ	Rotor solidity ratio = $bc/\pi R$
ΩR	Rotor tip speed, fps

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